The Use of Vortex Wake Theory for the Analysis of Airflow Around Rotorcraft

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The U. S. Army has a requirement to understand the behavior of airflow below and around the rotor of a helicopter. Knowing how the air behaves will allow the Army to better address a number of issues and problems currently being faced to better allow it to perform its required missions. Issues include the understanding of the wake influence on a missile, rocket or jettisoned store as it passes through a chaotic airflow. In addition the Army also has a requirement to understand the propagation and flow of chemical agents in the rotor flow field as the agents are dispersed and deposited on and around the aircraft. The Flight Test Simulation Station (FTSS) at the U.S. Army Aviation Technical Test Center has developed the capability to analyze potential airflows around rotorcraft using vortex wake analysis. As part of the simulation based acquisition process, this capability within the FTSS is but one of the many analytical components being employed to support ongoing aviation projects.

FTSS is a variable fidelity rotorcraft simulation and analysis capability and can be performed with either pilot or engineer-in-the-loop. FTSS has software which kinematically models any type of rotorcraft and performs analysis in the areas of performance, stability, handling qualities, loads, vibrations, aeromechanics and rotor wakes to name a few. This presentation will focus on the area of rotor wakes. FTSS does not have a Navier-Stokes solver nor an Euler solver, to solve viscid or inviscid rotational flow, however FTSS employs the most sophisticated rotor vortex wake solvers used by the rotorcraft industry and is capable of determining the airflow pattern in the vicinity of the fuselage and empennage. FTSS employs two inflow theories, momentum and vortex wake. There are three types of vortex wakes that can be used in an analysis depending on the flight condition. Prescribed wake is used when the helicopter is in a hover, whereas rigid wake and free wake are used in forward flight when the advance ratio is greater than .05. The Biot-Savart equations are solved for each vortex wake type and the velocity flow field around the helicopter can readily be determined upon solution of the wake structure. The assumptions are that the fluid is inviscid, irrotational, incompressible and adiabatic. Both momentum theory and vortex wake theory assume the problem is steady state and that mass is conserved. Essentially, the vortices, which are trailed, shed and spiral behind the rotor blade are mathematically and geometrically recreated to provide the velocity vector for any given distance in 3-D space away from the rotor. Each of the four main rotor blades generates trailed and shed type vortices for both the near and far wake structure.

For this presentation there were four specific cases looked at. The first is the rotor in a straight and level forward flight condition at 20 kt. The thrust for this case is approximately 13,300 lb. and the average induced velocity at the rotor disk is 35 ft/s. The results show how the wake has a slight skew angle from being blown back and is beginning to roll up. The second case is the rotor in a straight and level forward flight condition at 120 kt. The thrust for this case is approximately 15,500 lb. and the average induced velocity at the rotor disk is 38 ft/s. For this case the results show how the wake is being blown much further back and has completely rolled up onto itself and is starting to look like a fixed wing wake. The third case is the rotor in a forward flight condition at 10 kt and a descent rate of 1200 ft/min. At that rate of descent the rotor is in the vortex ring state. The results show that the upwash through the rotor disk is compressing the wake so it is much shorter in length than it normally would be. The thrust for this case is approximately 9,500 lb. and the average induced velocity at the rotor disk cannot be determined since momentum theory is not valid under this flight condition. The final case is the rotor in a hover. The thrust for this case is approximately 15,250 lb. and the average induced velocity at the rotor disk is 37.5 ft/s. The plots show how the wake contracts to approximately 75 percent of the rotor radius at approximately 1.5 rotor radii beneath the rotor. The results for rotor performance from the free wake analysis showed excellent correlation with flight test data from the U. S. Army Aviation Technical Test Center (ATTC). More specifically, the power required predicted is within one percent of the actual flight test data. In addition a case study was done as part of the verification studies to show how many revolutions were needed to improve the convergence of the free wake to a suitable point. Since adding revolutions to the free wake increases the run time an optimal solution must be found.